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ABSTRACT

Two instructional design variables directly related to concept learning were investigated. The first variable, management strategy, tested the hypothesis that advising students of their learning need in relationship to acquisition of a task at a given criterion would be more effective than either adaptive control or learner control strategies. Data analysis showed that for college students, the advisement condition resulted in better performance than the learner control and needed less instructional time and fewer instructional instances than the adaptive control. The second variable contrasted two forms of content structure used in learning coordinate concepts: simultaneous and successive. Students given concepts simultaneously performed better on the posttest and needed less instruction than those who received concepts successively. (Author/CTM)

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Instructional Control Strategies and Content
Structure as Design Variables in Concept
Acquisition Using Computer-Based Instruction

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Abstract

Two instructional design variables directly related to concept learning were investigated. The first variable, management strategy, tested the hypothesis that advising students of their learning need in relationship to acquisition of a task at a given criterion would be more effective than either adaptive control or learner control strategies. Data analysis showed that for college students, the advisement condition resulted in better performance ($p < .001$) than the learner control and needed less instructional time ($p < .005$) and fewer instructional instances ($p < .001$) than the adaptive control. The second variable contrasted two forms of content structure used in learning coordinate concepts. Students given concepts simultaneously performed better on the posttest ($p < .001$) and needed less instruction ($p < .005$) than those who received concepts successively.

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One of the concerns of research in the control of the learning environment is adaptive education or the adaptability of the instructional presentation to the individual differences of learners. The term adaptive instruction, however, has frequently been used to describe quite different things (Tennyson & Rothen, 1979). According to Glaser (1977), it combines the development of an individual's initial competence with alternative environments matched to different styles of learning. Landa (1976) defines adaptive instruction as a diagnostic process aimed at adjusting the instructional context to the unique learning needs of each student. For Rothen and Tennyson (1978), it implies a diagnostic process which assesses a variety of learner indices (such as general aptitudes related to the learning task and prior task achievement) and characteristics of the learning task (such as difficulty level, content structure and conceptual attributes) in order to prescribe an initial instructional program which can be adjusted continuously to student on-task learning needs.

In contrast to these structured adaptive instructional methods, in which the amount and sequence of the instructional stimuli are made without strategy inputs from the student, the learner control method allows the student to be responsible for the learning strategy. Although learner control, in this way, seems to exhibit the elements of adaptability, instructional research dealing with variables of learner control (using rather large on complex learning tasks) have failed to demonstrate that students can make and carry out decisions of content element selection and personal learning assessment (DiVesta, 1975). In

experimental learning tasks which required minimal prior knowledge and included a simple content structure, the learner control strategy usually resulted in less time on-task (with equivalent performance) than did a form of program control (Steinberg, 1977). However, in tasks consisting of a complex content structure and demanding greater prerequisite knowledge, the outcomes were almost entirely in favor of program control (see Tennyson & Rothen, 1979, for a complete review).

Given the current inadequacies of learner control methods of instructional management (especially for computer-based instruction), Tennyson and his associates designed (Rothen & Tennyson, 1978; Tennyson & Park, in press; Tennyson & Rothen, 1979) and tested (Tennyson & Rothen, 1977; C. Tennyson, R. Tennyson, & Rothen, in press; Tennyson, Park, & Rothen, in press; Lau & Tennyson, Note 1; Tennyson & Buttrey, Note 2; Tennyson & Jassal, Note 3) an adaptive instructional management strategy. This management strategy uses a Bayesian statistical method to integrate (a) assignment of a specific treatment based upon a premeasure of cognitive ability; (b) an initial amount of instructional support based upon a pretest measure of prior achievement; and (c) adjusted amount of instructional support and sequence based upon on-task learning need. The studies cited have demonstrated the effectiveness of this Bayesian probabilistic adaptive instructional strategy in selecting the appropriate amount and sequence of instruction for learning concepts. However, if a student is provided meaningful information on-task ~~about~~ his or her own learning development, the cognitive strategy used by the student may further refine the diagnosis and prescription made by an adaptive management system.

In the present study, I propose an extension of the learner control management strategy by combining learner control with diagnostic and prescriptive

information generated from the Bayesian adaptive instructional strategy. Operationally, this implies several things. First, at the start of their instruction students are advised of (a) their initial level of concept attainment compared to the desired learning criterion (diagnosis) and (b) the amount and sequence of instruction necessary for them to obtain the objective (prescription). Second, students are continuously advised while on-task of their learning development (updated diagnosis) and the instructional needs (updated prescription) necessary for concept mastery. Finally, since this is a learner control management strategy, students make decisions on both amount and sequence of instruction. For the independent variable of management strategy, I hypothesized not only that the learner-adaptive control strategy (the condition using advisement) would be as effective in student acquisition of the learning task as the adaptive strategy (that is, students in both these strategy conditions would surpass the criterion of mastery), but also that it would be more efficient in terms of student on-task learning time. I furthermore hypothesized that both of these strategies (learner-adaptive control and adaptive control) would be more effective and efficient than the learner control strategy.

Psychological experiments on inductive concept formation which manipulate stimulus symbols such as nonsense syllables, pictures, and colors have already dealt with the presentation order of examples dealing with related concepts (Brown, 1974; Bruner, Goodnow, & Austin, 1956; Dominowsky, 1974; Milward & Wickens, 1974; Rosch, 1975; Sanders, DiVesta, & Gray, 1972). However, as a design strategy for actual concept teaching, the presentation order of examples for related (coordinate) concepts has not been examined until quite recently.

Investigating the learning of contextually similar rules, R. Tennyson and C. Tennyson (1975) showed that presenting rules simultaneously by pairing instances according to matched variable features resulted in significantly better performance than either a successive presentation of rules or a random presentation. More recently, C. Tennyson, R. Tennyson, and Rothen (in press) extended the presentation order of rule examples to the presentation order and content structure of coordinate concepts. The results of their study showed that presentation of concepts according to their coordinate relationships facilitates concept acquisition; students learn to discriminate between such concepts when given examples of each concept concurrently within rational sets.

The second purpose of this study was to replicate the C. Tennyson et al. study by applying the content structure variable to another discipline and population. While the C. Tennyson et al. study used four coordinate concepts from psychology, I selected coordinate concepts from physics; and while the earlier study's participants were high school students, I selected young adult college students of 19 to 21 years of age. Given the findings of R. Tennyson and C. Tennyson (1975) and C. Tennyson et al. (in press), I hypothesized that presentation of concepts according to their coordinate relationships would facilitate concept acquisition as contrasted to a design strategy that presents concepts successively.

Method

Students and Design

Participants ($N = 135$) were male and female undergraduate students (ages 19-21) from the University of Madrid (Spain) enrolled in introductory physics classes. From a random list of the six treatment conditions, students were assigned one treatment condition as they appeared for the experiment. They

were informed that credit was given for participation and that their professors would grade their posttest scores. This contingency was included to simulate an actual classroom-related incentive missing from most learner control studies. Without such a contingency, students in learner control situations tend to terminate early and thus learn less (Felixbrod & O'Leary, 1974). A strong incentive to master the material--in this instance a course grade--provides a better comparison between a program control condition (relatively captive audience) and a learner control condition.

Learning Program

The coordinate concepts selected for this study, drawn from the field of physics, were force, power, velocity, and speed. Subordinate concepts consisted of molecular molecule and atom structures. A superordinate concept dealt with energy. Examples used in the learning program and accompanying tests were written according to the concept design strategy developed by Merrill and Tennyson (1977). The level of difficulty for each example was determined by an instance probability analysis (using 24 students in the formative evaluation) according to procedures outlined by R. Tennyson and Boutwell (1974). Of 92 instances in the learning program, 40 were used in the instructional lessons, 24 in the pretest, and 28 in the posttest. The instructional instance pool contained 10 instances of each concept. Thus, at maximum, a student could receive 68 instances before taking the posttest. Each treatment group employed the same instance pool. The learning program retained the same response format as the two tests; however, in the learning program the student received feedback on whether or not the response was correct.

To validate the learning program, I used a formative evaluation procedure for assessing instructional materials (Tennyson, 1976). First, several

subject matter experts reviewed the definitions and instances. Then, after appropriate revisions of the definitions and instances, a one-to-one tryout of each learning program was conducted with six randomly selected students from the sample population, followed by simulation tryouts of each treatment condition (six students per treatment). From this tryout data final refinements on the learning program and computer software were made.

Adaptive Management Strategy

To study the management strategy variable, I used for the adaptive control strategy a computerized Bayesian statistical model developed by Rothen and Tennyson (1978). This model determines the number of examples which each student receives from three parameter values: achievement level, a mastery criterion (.7), and loss ratio (1.5), which is defined as the disutilities associated with a false advance compared to a false retain decision. The estimate of the student's ability to learn a concept was characterized in probabilistic terms. From the initial achievement level, which was determined by the pretest score, and the other two parameter values, the probability was used to decide the initial number of instances that the student needed. This probability figure was adjusted according to the student's on-task performance level, and the prescribed number of instances was modified. Student performance on each concept was calculated separately with a criterion level set at 1.0 on the initial assessment. That is, if the student answered all six instances of any concept correctly on the pretest or the initial part of the learning program, he or she received no more examples of that concept unless it was needed for discriminating coordinate concepts (for a complete review of this response-sensitive procedure see Tennyson & Park, in press, or Tennyson, Park, & Rothen, in press). If the students did not achieve total mastery on the initial

assessment, the criterion level was adjusted to suggest a prior distribution slightly greater than .5 to the region above the criterion level:

$P = (\pi \geq \pi_o / \underline{x}, \underline{n}) > .5$, where π_o is the objective's criterion level, π is the student's true achievement level, $\underline{n}$ is test length, and $\underline{x}$ is the student's score (Tennyson & Rothen, 1979).

Learning Program

The two independent variables of management strategy (three conditions: adaptive control, learner control, and learner-adaptive control) and content structure (two conditions: simultaneous and successive) were tested with a pretest-posttest, two-way factorial design (six treatment groups). In determining the presentation of the instructional stimuli, the adaptive control strategy selected (a) the number of instances presented to each student based on the student's pretask and on-task performance in relationship to the learning objective, and (b) in the simultaneous condition, the sequence of instances according to the student's response pattern to the given example. Following the pretest, students in the adaptive control condition were given program directions and informed that they would receive a posttest at the conclusion of the instruction. In the learner control strategy, the students decided (a) whether to continue receiving instances or to go to the posttest, and (b) in the simultaneous condition, which concept they wanted to see next. Students were informed in the program directions that they had complete control on amount and sequence (simultaneous condition) of instruction. (Note: In the successive condition, the students could either continue to receive examples or go on to the posttest; they were not informed which concept was being presented.) The third management strategy condition, learner-adaptive control, used a learner control management strategy that (a) allowed students to decide whether or not to continue receiving instruction, and (b) advised them on the number of instances needed to reach

mastery for each concept (diagnosis and prescription information determined by the Bayesian model). For the simultaneous condition, students were also advised which concept example to select next--as distinct from the successive condition, which only advised students on number of instances. Program directions (a) informed the students of the learner control format and (b) told them that the advisement information was determined according to their individual learning development in relation to mastering the concepts and would aid them in deciding amount and sequence of instruction (for the simultaneous groups only).

For the second independent variable, content structure, the two conditions, simultaneous and successive, were operationally designed as follows: In the simultaneous condition one example from each concept was arranged so that variable attributes were similar within a set but different between sets. Once concept mastery was obtained, examples from that concept were dropped from succeeding rational sets, except when they were needed for discrimination learning (Tennyson, Park, & Rothen, in press). In contrast, the successive condition presented concepts one at a time. Once mastery was obtained for a given concept, the next concept followed, and the process was repeated until all four concepts had been presented.

The six computer-based instructional treatment groups developed from the two independent variables are summarized in Table 1.

 Insert Table 1 about here

Facilities

The experiment was conducted in the Information and Automation Research Laboratory of the Department of Physics at the University of Madrid, Spain.

Three Hewlett-Packard CRT terminals were used for the study. Each terminal, operating at 30 characters per second, was connected to the laboratory's Hewlett-Packard computer. Individual student carrels allowed for individual starting and ending times.

Procedures

As students reported for the experiment, each was assigned to a treatment program. The experimenter turned on the terminal and entered each student's treatment program number. After receiving directions on operating the terminal, students were first administered a 30-item syllogism test (French, Ekstrom, & Leighton, 1963) followed by a 24-item pretest. When the pretest was finished, students received a print copy of the four concept definitions from the experimenter; they were able to refer to these definitions during the learning program. After studying the definitions, students raised their hands to indicate readiness to study the examples in the learning program. The experimenter entered the appropriate command on the terminal for students to begin the learning program. After a student classified an example in the learning program, he or she received feedback on whether the classification was correct or incorrect. When each student finished the learning program, the experimenter took the definition sheet and entered the appropriate command on the terminal for the posttest to begin. All student entries were single-letter alphanumeric responses to multiple-choice styled questions. The tests and learning program required no other entries by the student. After the students had finished, the experimenter thanked them, and they left the experiment room. Others were then signed on to the terminal.

Results

The data analysis consisted of a multivariate analysis of variance with univariate tests on each dependent variable followed by mean comparison tests

(Student-Newman-Keuls). Multivariate dependent variables consisted of the correct score on the posttest and time on-task (the measured time period in which students interacted with the learning program, excluding pretask and posttest times). The tests for homogeneity of regression of within-class and between-class linearity were nonsignificant ($p > .05$). Means and standard deviations for the dependent variables of posttest correct scores and time on-task by treatment conditions are presented in Table 2.

 Insert Table 2 about here

The multivariate test on the main effect of content structure was significant, $U(1, 1/2, 133) = .77, p < .01$. The test on the second main effect, management strategy, was likewise significant, $U(2, 0, 13) = .39, p < .001$. The interaction test between the two independent variables was nonsignificant ($p > .05$). Following are the univariate test results on each of the dependent variables.

Posttest Correct Score

The analysis of variance test on the posttest correct scores (Table 2) showed a difference between the two content structure conditions, $F(1, 27) = 7.03, p < .005$. Students in the simultaneous condition ($M = 20.8$) had a posttest score of four points higher than students in the successive condition ($M = 16.4$). In percentage correct, the simultaneous condition was 74% while the successive was only 58%. For the main effect of management strategy, the F test was significant, $F(2, 127) = 16.48, p < .001$. Mean correct score for the adaptive control condition ($M = 20.5$) was equivalent to the learner-adaptive control condition ($M = 20.8$), both which were six points higher than the learner

control condition ($\bar{M} = 14.7$). In terms of percentage correct, the learner control condition was at 53% with the other two conditions at 73%.

The Student-Newman-Keuls multiple range test was used to analyze posttest correct mean score differences between the six treatment groups. At the .05 level, the adaptive control/simultaneous group (82% correct) and learner-adaptive control/simultaneous group (85% correct) were together different from the other four groups. In addition, the adaptive control/successive group (64% correct) and learner-adaptive control/successive group (64% correct) had higher posttest scores than the two learner control groups (learner control/simultaneous, 56% correct; learner control/successive, 49% correct). The pretest correct mean score F test was nonsignificant ($p > .05$).

Time

Average time spent on the pretest was 7.3 minutes; time spent on the posttest averaged 9.3 minutes. No significant differences appeared between groups in the pretest or posttest times ($p > .05$). The analysis of variance test on the two content structure conditions for time on-task was nonsignificant ($p > .05$). The difference in time required between the fastest (simultaneous, $\bar{M} = 9.5$ min.) and the slowest (successive, $\bar{M} = 11.4$ min.) groups was less than two minutes. However, time on-task mean differences between the three management strategy conditions was significant, $F(2,127) = 11.56$, $p < .01$. In length of time on-task, the adaptive control condition ($\bar{M} = 13.4$) was 43% greater than the learner control ($\bar{M} = 7.7$), while the learner-adaptive control condition ($\bar{M} = 10.3$) was only 25% greater than the learner control condition. A Student-Newman Keuls test on the six group means for time on-task showed that the two learner control management strategy groups (Groups 3 and 4) spent significantly less time on-task ($p < .05$) than the other four

groups. Additionally, the two learner-adaptive control groups (Groups 5 and 6) were no different ($p > .05$) than the adaptive control/simultaneous group (Group 1); however, these three differed ($p < .05$) from the adaptive control/successive condition (Group 2).

The difference in time on-task is directly related to the number of examples presented in the learning program. Given the importance of amount of stimuli needed for development of instruction, I tested this additional dependent variable. For the main effect of content structure, the number of examples for the simultaneous condition ($M = 17$) was significantly less than in the successive condition ($M = 26$, $F(1,127) = 9.87$, $p < .01$). There was likewise a difference between conditions for the management strategy variable, $F(1,127) = 19.44$, $p < .005$. The adaptive control condition ($M = 29.3$) required the greatest number of examples, and the learner-adaptive control condition ($M = 23.2$), required more than the learner control condition ($M = 16.7$). In other words, while students in the learner control condition used, on the average, only 41% of the possible examples, the learner-adaptive control condition students used 58%, and the adaptive control condition required 73% of the available instructional examples.

Discussion

The results of this study replicate the findings of previous research in which Tennyson and his associates found that manipulation of the elements in a content structure can directly influence a student's level of concept attainment (for a complete review, see Tennyson & Park, in press). In terms of post-test performance, students who were presented with the simultaneous order of coordinate concepts surpassed the .7 mastery condition, while students in the successive order had posttest performances at the .5 level. Of the two presentation orders, only the simultaneous condition used an instructional method

to focus student attention on the differences between critical attributes of coordinate concepts. Students in the simultaneous condition learned not only to generalize within a concept class but also to discriminate between concept classes. Amount of instruction required for learning concepts, while not a usual dependent variable, is important here because learning from instruction is not merely a function of exposure to a continuing flow of stimuli. This study showed that students in the simultaneous condition averaged 35% less instructional stimuli than in the successive condition. In other words, students receiving the simultaneous presentation of coordinate concepts needed significantly fewer instructional examples (while performing better on the posttest) than students who received more examples in the successive condition.

Research on learner control variables has not produced instructional design variables of a generic nature. That is, learner control seems to be a useful management format once the correct contingency is identified, and this seems to have been successful only in highly defined occupational areas (Steinberg, 1977). Too often those contingencies associated with school-related learning--such as grades, praise, or rewards--vary in relationship to personal variables, such as sex, age, race, and home environment. Often this results in variables and conditions too confusing for practical application or theoretical development. One purpose of the study was to introduce a variable to the basic learner control management strategy unlike that of previous research variables. This dealt with actual on-task learning development--advising students of both their learning progress (diagnosis) and their individual learning need (prescription) in reference to mastering the objective. Students would thus have meaningful information on which to make judgments concerning the amount and sequence of instruction.

The variable of advisement, as operationally defined, was highly significant in providing students in the learner-adaptive control condition with meaningful information with which to make appropriate decisions about acquisition of the coordinate concepts. On the posttest, students in the learner-control adaptive condition did as well as the students in the adaptive control condition (each group receiving 74% correct). The significance of this result is apparent in contrast to performance in the learner control condition, where students responded to only 52% of the posttest items correctly (identical to the pretest). This outcome of the learner control condition is consistent with previous research, which has shown that even with a strong contingency, such as a grade, students learn little from the instruction; research has furthermore shown that no matter what level of on-task attainment is reached, all students leave the instruction at approximately the same time.

The dependent variable of time is important to consider in the study of learner control management strategies because students in a learner control condition consistently leave instruction before mastery of the objective. In contrast to this basic finding, students in the study who received advisement (learner-adaptive control condition) stayed on-task long enough to obtain mastery. They were on-task approximately 26% longer than the students in the conventional learner control condition. It was my thesis that if students in a learner control strategy were given advisement in the form of adaptive-diagnostics/prescriptions, they would master the objective in less time than in a program controlled adaptive system. The assumption was that the cognitive strategy which students used in learning would further refine the adaptive information. The findings support this notion: the two conditions using the adaptive information (adaptive control and learner-adaptive control) had

identical posttest score means, but the learner-adaptive control condition showed a significant 24% decrease in on-task time.

In conclusion, a learner control condition can be a valuable instructional management system, especially for computer-based instruction, if students receive sufficient information about their learning development--information which continuously shows them what progress they have made towards mastery of the objective and provides meaningful advice on appropriate stimuli necessary to obtain it.

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Table 1
Treatment Groups by Management Strategy
and Content Structure

Management Strategy	Content Structure	
	Simultaneous	Successive
Adaptive control	Group 1: No student control Examples presented in rational sets	Group 2: No student control Concepts presented separately
Learner control	Group 3: Student control on amount and sequence Examples presented in rational sets	Group 4: Student control on amount and sequence Concepts presented separately
Learner-adaptive control	Group 5: Student control on amount and sequence Advisement on diagnosis and prescription Examples presented in rational sets	Group 6: Student control on amount and sequence Advisement on diagnosis and prescription Concepts presented separately

Table 2
Means and Standard Deviations for
Posttest Correct Scores and Time On-Task

Management Strategy	Content Structure			
	Simultaneous		Successive	
	Score	Time (min.)	Score	Time (min.)
Adaptive control				
<u>M</u>	23.0	11.8	17.9	15.0
<u>SD</u>	3.1	2.9	3.9	4.9
Learner control				
<u>M</u>	15.8	7.4	13.6	7.9
<u>SD</u>	4.9	2.6	4.4	2.7
Learner- adaptive control				
<u>M</u>	23.8	9.3	17.8	11.3
<u>SD</u>	3.7	2.8	4.3	4.2

Note. Maximum posttest score = 28.